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ABSTRACT

The operational requirements of the National Ignition Facility (NIF) place tight constraints upon its alignment system. In general, the alignment system must establish and maintain the correct relationships between beam position, beam angle, laser component clear apertures, and the target. At the target, this includes adjustment of beam focus to obtain the correct spot size. This must be accomplished for all beamlines in a time consistent with planned shot rates and yet, in the front end and main laser, beam control functions cannot be initiated until the amplifiers have sufficiently cooled so as to minimize dynamic thermal distortions during and after alignment and wavefront optimization. The scope of the task dictates an automated system that implements parallel processes. We describe reticle choices and other alignment references, insertion of alignment beams, principles of operation of the Chamber Center Reference System and Target Alignment Sensor, and the anticipated alignment sequence that will occur between shots.

Keywords: alignment references, alignment sensors, automatic alignment, laser alignment, NIF

2. OVERVIEW

The automatic alignment control system is designed to establish and maintain laser chain alignment from the output of the optical pulse generator to target chamber center. It accomplishes this task by operating thirty-three motors on seventeen mounts to control the tip, tilt, and longitudinal positions of twenty optical elements in the each of the one hundred ninety two NIF laser chains. Beam center and orientation are defined in the preamplifier module (PAM) by near field references inserted at the apodizer plane in the beam shaper assembly, and fiber sources identify subsequent aperture centers and orientations. Beam pointing is defined primarily by far field references in the NIF spatial filters.

Comparison of near field reference images provides centering and orientation error signals as depicted in Figure 1. The point midway between the two sources designates the aperture center (x,y), and line between the centers of the sources designates aperture orientation (ϕ). Some centering references are permanently mounted on the beam centerline but outside the beam path. Others are mounted on remotely controlled actuators and are inserted into beamlines during automatic alignment. Mirror motions are used to superimpose all of these designators, thus centering and orienting the beam at each reference.

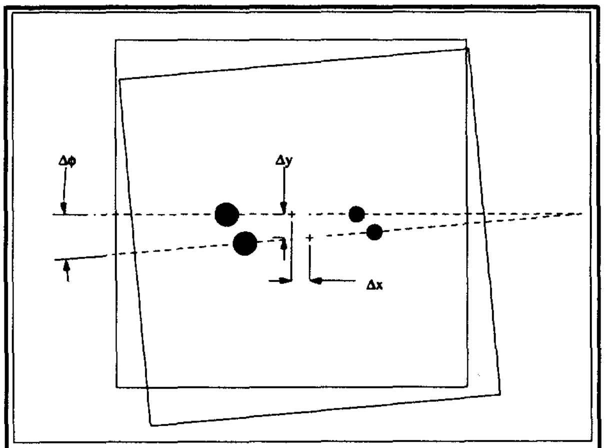


Figure 1: Cameras view laser chain relay planes, recording the locations of centering designators.

Comparison of two far field images, one of a reference, the other of an alignment laser, provide pointing error signals. All but two of the far field references are located inside spatial filters, as depicted in Figure 2. The beam angle relative to the optical axis of a spatial filter can be deduced if the location of the beam focus in the pinhole plane is known. The location of the beam focus and pinhole center for a given pass are extracted from pinhole plane images of an alignment beam and reticle. Motion of mirrors located outside the spatial filter may be used to null the beam displacement from the center of the far field reference, thus correcting the beam pointing through the shot pinhole for the corresponding pass.

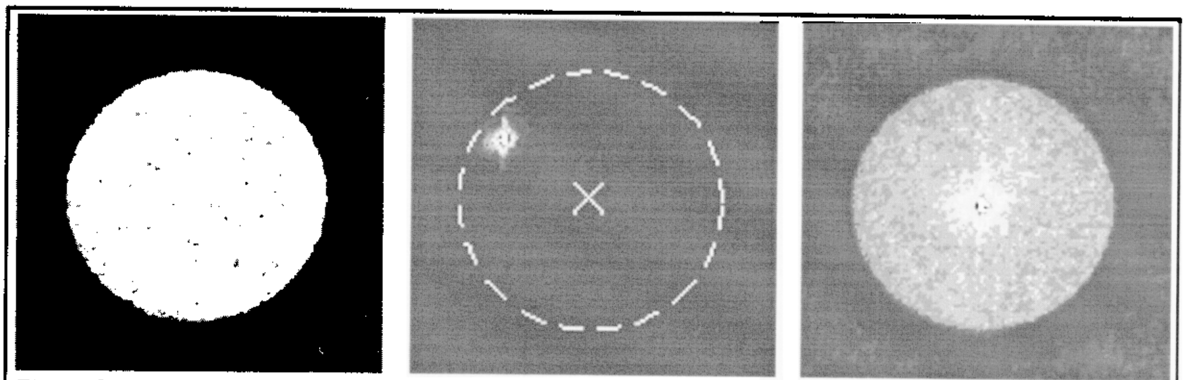


Figure 2: A camera views the pinhole plane, recording locations of the reticle and the alignment laser. (a) The center of the reticular mark coincides with the center of the pinhole. (b) The position of the alignment beam relative to the pinhole center is found by viewing the beam scatter off the reticle. (c) The alignment beam is pointed through the pinhole center by changing the angle at which it enters the spatial filter.

The 1053 nm (1ω) light from the Main Laser is frequency upconverted to 351 nm (3ω) before being directed onto targets. The final lens in each beam is designed to focus 3ω light at target chamber center. 1ω light will focus past target chamber center and thus cannot be used for target alignment. The irradiance of the alignment laser is too low for appreciable upconversion, therefore it cannot be used to produce a 3ω alignment beam. Fibers are used to inject 3ω light downstream from the final amplifier, in the 3ω focal plane of the final spatial filter output lens. Introduction of the target alignment source at this location in the chain increases the availability of parallel automatic alignment processes since doing so eliminates the need to wait for amplifier cool down prior to aligning beams to the target. A translatable stage is responsible for precisely positioning an output-coupled fiber on the axis of the pass 4 pinhole in the 3ω focal plane of the final spatial filter lens. The 3ω light emerges collimated from the spatial filter and follows the beamline through the final optics assembly into the Target Chamber.

The Chamber Center Reference System (CCRS), consisting of two high resolution viewers mounted outside windows at orthogonal Target Chamber ports, provides a stable target chamber coordinate system. The position and orientation of the Target Alignment Sensor (TAS) in this coordinate system are sensed and automatically controlled for each shot. The TAS provides superimposed views of the target and the 3ω beams without allowing any beams to preheat the target. A five degree of freedom positioner is used to place the target in the center of the TAS, and the final transport mirror on each beam is controlled to position the beam at the desired position on the target.

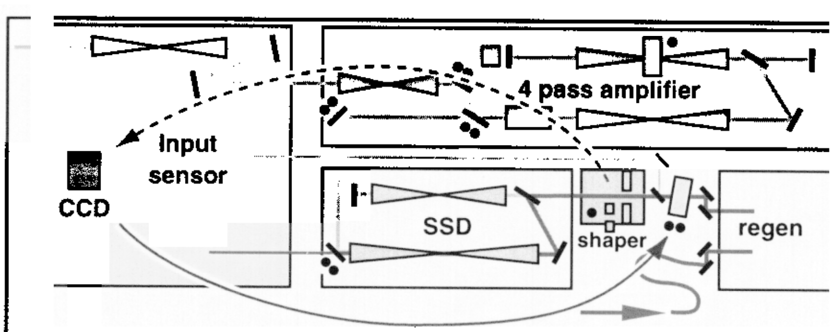
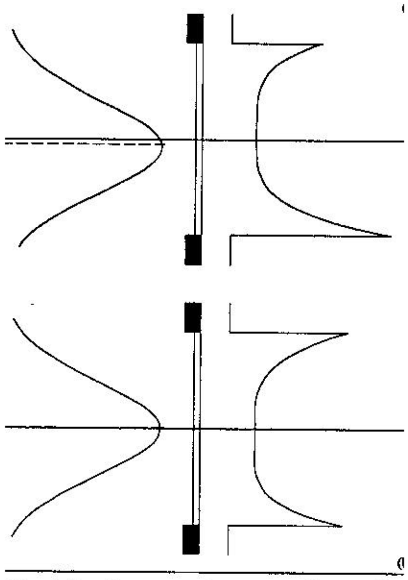


Figure 3: The automatic alignment system uses the Input Sensor's near field view of the Beam Shaper output to calculate corrections of the tip and tilt of the Centering Adjustment Glass. The tilt of the parallel plate serves to move the beam to a different but parallel axis of propagation

3. PULSE GENERATOR ALIGNMENT

The alignment system is required to adjust the position of the regenerative amplifier output (regen) beam in the Beam Shaper aperture so as to minimize the difference between measured and desired spatially shaped irradiance profiles. This is accomplished using images collected in the Input Sensor. A small sample of the light emerging from the beam shaper is collected and relayed to the Input Sensor camera where it forms an image of the plane containing the apodizer. The centering offset is extracted by image analysis, and can be nulled by tilting the Centering Adjustment Glass located in the beam path immediately downstream from the regen. The automatic alignment system includes a closed loop that performs this task, as depicted in Figure 3.



igure 4: Regen pulses pass through e beam shaper. (a) Decentered pulse) Centered Pulse.

Simulated Beam Shaper output is shown in Figure 4. In the case of a decentered input beam, the output beam is asymmetric. The amount of decenter may be calculated by deconvolving the input beam profile from the near field image. The input beam profile is gaussian, any deviation from this will be evident in a sample of the regen output collected immediately in front of the beam shaper. In the case of a centered input beam, the output beam is symmetric.

The spatially shaped pulse emerges from the Beam Shaper and enters a Smoothing by Spectral Dispersion (SSD) module. The output of the SSD is imaged by the Input Sensor. It is this near field image of the apodizer plane that is used during centering of the regen output in the Beam Shaper.

Once the proper Beam Shaper output has been verified, the light from the SSD is directed into the 4-pass rod amplifier (4-pass).

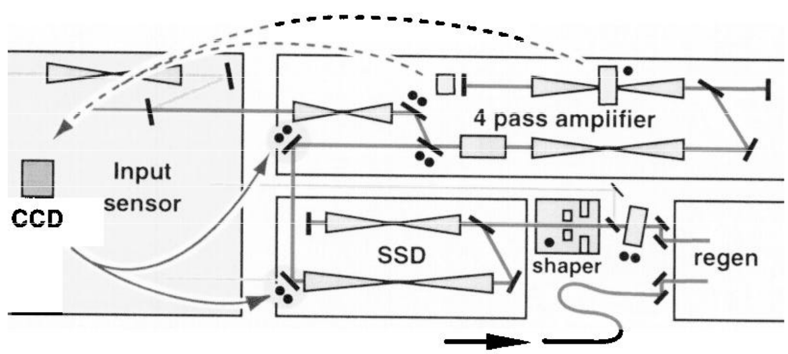


Figure 5: The automatic alignment system uses the Input Sensor's near field view of the fiber sources mounted behind the 4-pass end mirror to calculate centering corrections for the SSD output mirrors. The automatic alignment system uses the Input Sensor's far field view of the pass 1 reticle in the 4-pass spatial filter pinhole plane to calculate pointing corrections for the SSD output mirrors .

The 4-pass is aligned using the SSD Output Mirrors and images from the Input Sensor as depicted in Figure 5. The centering reference light source pair located behind the 4-pass end mirror is activated. The centers of these sources lie on the horizontal centerline of the 4-pass, and are equidistant from the vertical centerline. These light sources are visible in the image of the mirror surface relayed to the Input Sensor camera. They define the optimal beam center and orientation in the 4-pass.

Once the Input Sensor camera has captured an image of the 4-pass centering references, they are deactivated. Then the Beam Shaper Centering Reference Plate is moved into the beam path at the Apodizer plane. This plate has two openings. The centers of these openings lie on the horizontal centerline of the apodizer, and they are equidistant from the vertical centerline. These holes and the line containing their centers define beam centerline and orientation. Regen pulses strike the plate, illuminating the holes. The image of the illuminated holes is relayed through the SSD module, through the 4-Pass, to the Input Sensor camera, and a second image is captured. Offsets between the Beam Shaper hole centers and the reference light centers are nulled by moving the SSD output mirrors.

During far field alignment, a reticle is placed at the pass 1 position in the pinhole plane of the 4-pass spatial filter. This reticle is viewed from the Input Sensor looking back through the 4th, 3rd, and 2nd passes. The reticle is illuminated with an incoherent light source and an image is captured by the Input Sensor camera. Image analysis yields the location of the pinhole center in the image. The reticle is viewed at regen shot time. This image yields the actual beam pointing in the 4-pass. Offsets are nulled by moving the SSD output mirrors.

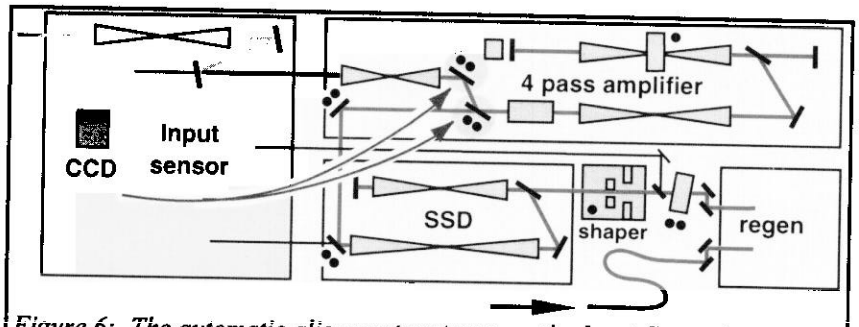


Figure 6: The automatic alignment system uses the Input Sensor's near field view of the Input Sensor near field reference to calculate centering corrections for the 4-pass output polarizers. The automatic alignment system uses the location of the focused spot on the Input Sensor camera to calculate pointing corrections for the 4-pass output polarizers.

After leaving the 4-pass, the light enters the Input Sensor, and the sensor's centering reference is inserted. The image of the Beam Shaper Centering Reference Plate is superimposed on the image of the Input Sensor centering reference by moving the polarizer pair located downstream from the 4-pass. No reticle is used in far field alignment of the Input Sensor. The center of the Input Sensor camera is itself the far field reference in this case. Pointing offsets are nulled by moving the polarizer pair. Alignment of the 4-pass into the Input Sensor is illustrated in Figure 6.

A 100 mW 1ω laser will be used between NIF shots for wavefront and pointing correction in the Main Laser. This laser is injected into the beamline in the Input Sensor. Upon activation, its pointing and centering is automatically aligned to the Input Sensor alignment references.

4. MAIN LASER ALIGNMENT

Alignment of the Main Laser, depicted in Figure 7, is independent of the PAM alignment as long as the Input Sensor alignment source is available.

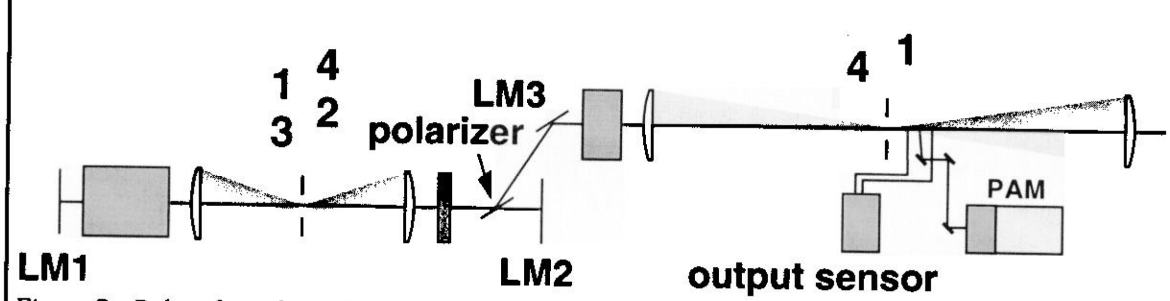


Figure 7: Pulses from the PAM are injected into the Main Laser near the pinhole plane of the Transport Spatial Filter (right). They are directed into the Cavity Spatial Filter (left). After four passes, the pulse emerges and passes through the Transport Spatial Filter on its way to the Target Chamber.

The required centering and Transport Spatial Filter (TSF) images are provided by the Output Sensor. The Cavity Spatial Filter (CSF) images are provided by the CSF camera. Fiber sources, permanently mounted outside the main beam path on the optical axis behind spatial filter pupil plane locations, are used as centering references. For all Main Laser alignment, the Pockels Cell must be bypassed. This is accomplished by inserting wave plates into passes 2 and 3 in the CSF.

The Main Laser alignment sequence is depicted in Figure 8-Figure 15. It begins with centering. The Automatic Alignment System views centering references located behind LM3 and LM1, and moves LM3 and the polarizer to center the image of the LM1 centering references on the LM3 centering references.

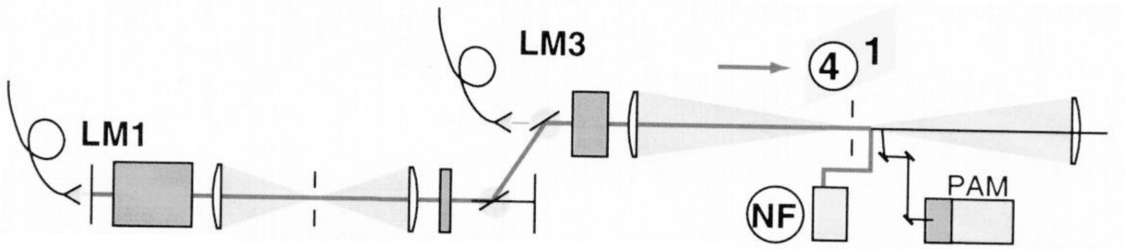


Figure 8: The automatic alignment system uses the Output Sensor in near field mode to view LM1 nd LM3, and then it moves LM3 and the Polarizer to match the LM1 light source pair to the LM3 light urce pair.

Then the automatic alignment system superimposes the image of the Beam Shaper centering references on the LM3 references by tilting the PAM output mirrors, nulling both centering and orientation errors.

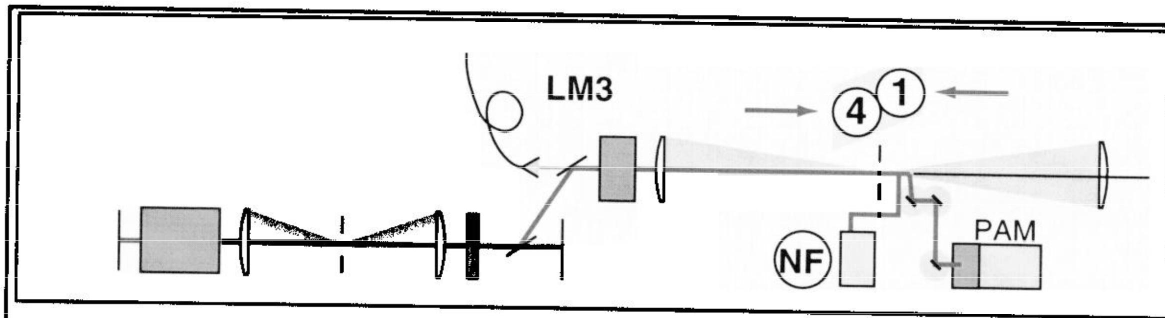


Figure 9: The automatic alignment system uses the Output Sensor in near field mode to view the Beam Shaper references, and then it moves the three PABST output mirrors to center the apodized beam on and orient the apodized beam to LM3.

Once centering and orientation have been accomplished, pointing begins. The TSF pass-1, the KDP, and the CSF passes 1-4 pointing systems consist of an incoherent illuminator, a pinhole plane reticle, and a CCD camera configured to view the pinhole plane. The reticle is a transmissive optic with a central diffraction grating in the shape of a pinhole. A precision positioner mechanism provides the ability to accurately place the reticle in the shot pinhole position. A portion of the illuminator light hitting the grating is directed to the off-axis CCD camera. Similarly, a portion of the focused beam is directed to the camera. The pinhole and beam images are used to derive pointing error signals as illustrated earlier in Figure 2. The images in Figure 2 were generated in the NIF alignment system simulator using a prototype diffractive optical element illuminated and viewed from off-axis.

For pointing alignment in the Main Laser TSF and CSF reticles are inserted. The PAM output mirrors are tilted to position the alignment beam on the TSF pass-1 reticle.

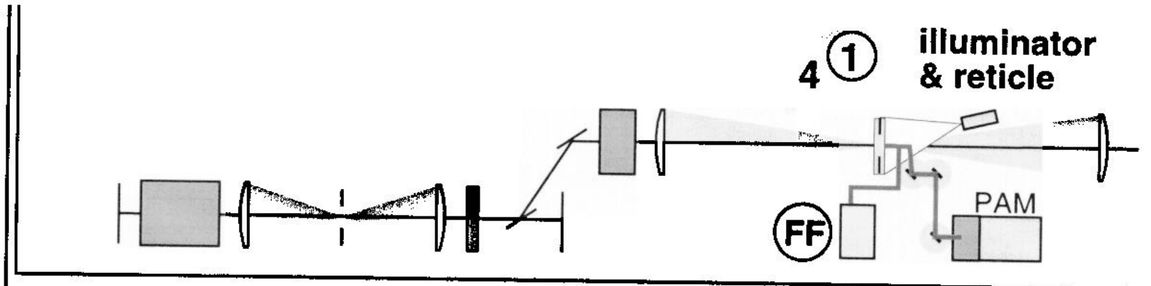


Figure 10: The automatic alignment system uses the Output Sensor in far field mode to view the TSF pass-1 reticle, and then it moves the three PABST output mirrors to point the alignment beam through the pinhole.

Then the automatic alignment system tilts LM1 to position the alignment beam on the CSF pass-3 reticle.

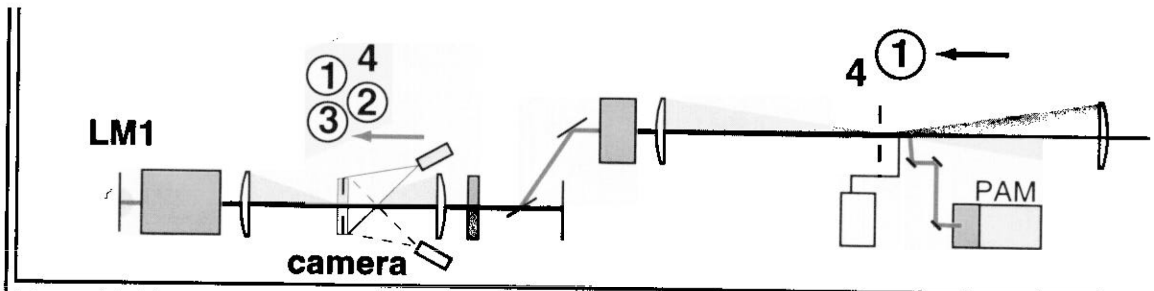


Figure 11: The automatic alignment system uses the CSF camera to view the CSF reticles, and then it moves LM1 to point the alignment beam through the pinhole.

After LM1 is positioned, LM1 and LM2 are moved together to position the alignment beam on the CSF pass-4 reticle without moving the beam on the CSF pass-3 reticle.

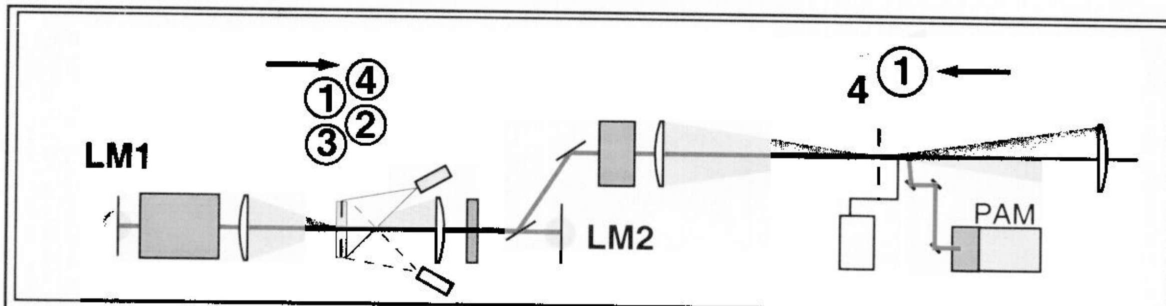


Figure 12: The automatic alignment system uses the CSF camera to view the CSF reticles, and then it moves LM1 and LM2 to point the alignment beam through the pass-4 pinhole while maintaining pointing through the pass-3 pinhole.

T he CSF output is aligned to the TSF pass-4 pinhole in a different fashion. A fiber is inserted into the center of the TSF pass-4 pinhole, and is viewed by the Output Sensor. Its location is recorded and it is removed.

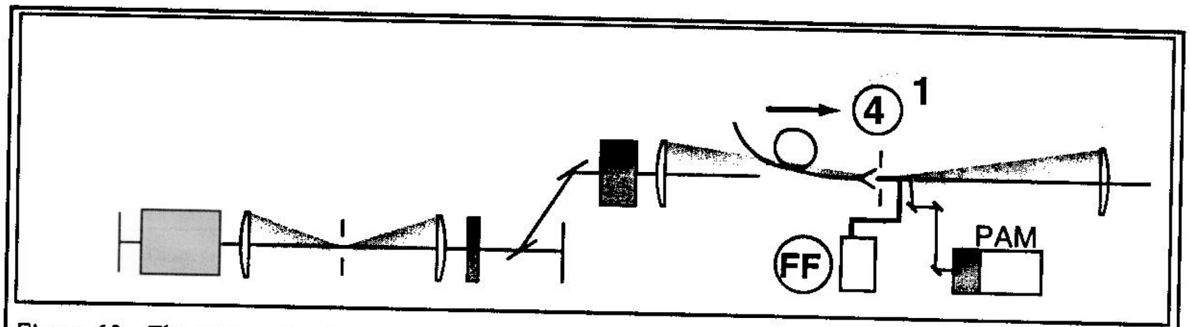


Figure 13: The automatic alignment system positions a fiber at the center of the TSF pass-4 pinhole, uses the Output Sensor in far field mode to view the fiber, and then removes the fiber. , and then it moves LM1 and LM2 to point the alignment beam through the pass-4 pinhole while maintaining pointing through the pass-3 pinhole

The alignment laser, having been steered through all four passes of the CSF, arrives at the TSF pass-4 pinhole. Its location is recorded and LM3 and the Polarizer are tilted so as to position the alignment beam at the fiber location. LM1 and LM2 must be adjusted at the same time to maintain the previous CSF alignment conditions.

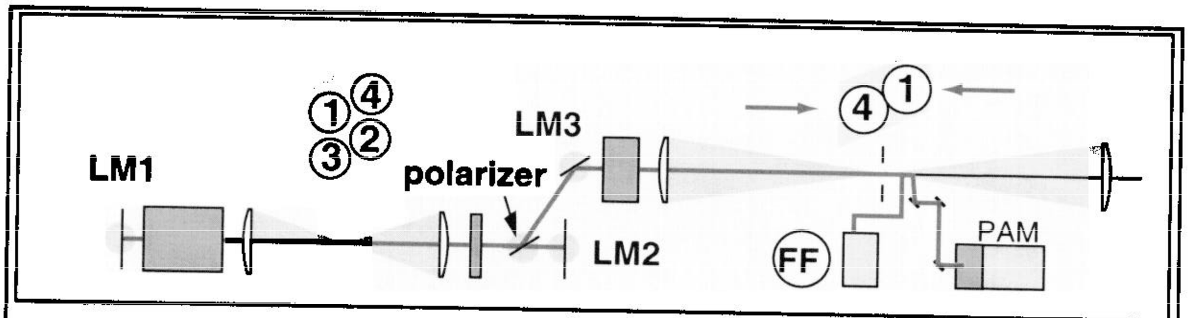


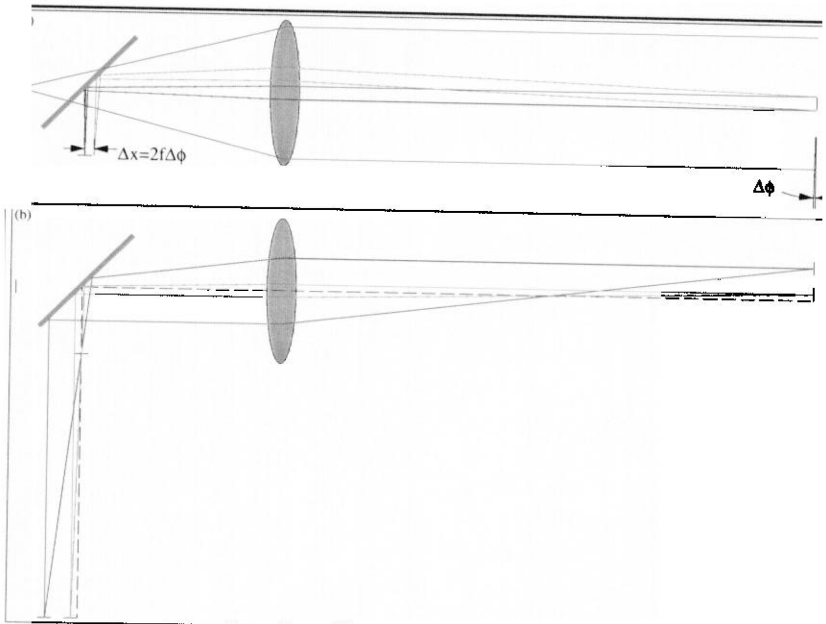
Figure 14: The automatic alignment system uses the Output Sensor in far field mode to view the TSF pass-4 pinhole and then moves LM3 and the polarizer to point the alignment beam through the pass-4 pinhole.

5. BEAM TRANSPORT

The Beam Transport and Target Area Alignment can be performed independently of the rest of the laser chain. In fact, since there are no amplifiers downstream of the TSF, it is to be expected that alignment in these areas will commence well in advance of the rest of the laser. Alignment begins with centering The final optics assembly alignment source pair is inserted and viewed through the TSF pass-1 pinhole. LM4, LM5, LM7, and LM8 are tilted in an adjustment that rotates the image of the final optics assembly alignment source pair to match the orientation of the LM3 sources then superimposes it on the LM3 sources.

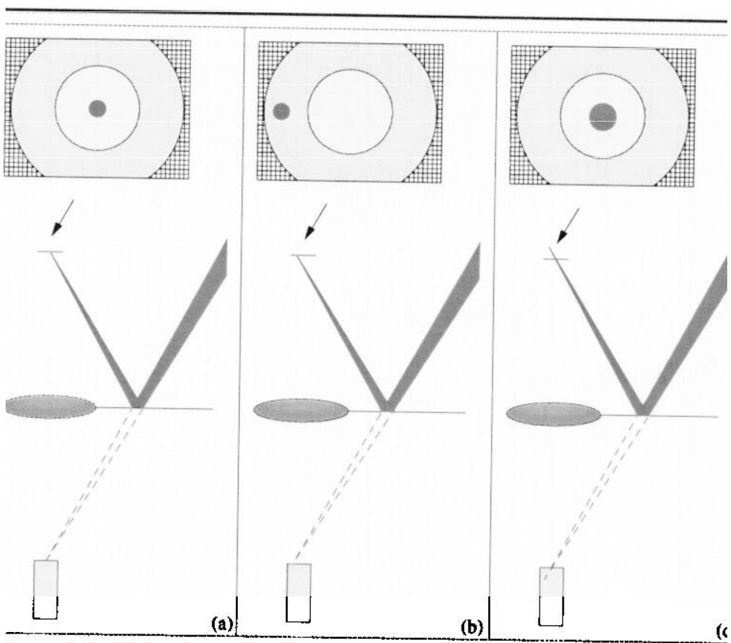
The conversion efficiency of the third harmonic generator (KDP) depends strongly upon the 1ω's angle of incidence at the final optics assembly. This angle is tuned by observing light reflected off a flat surface in the final optics assembly. This collimated light propagates back into the TSF, and the location of its focus at the TSF pinhole plane can be used to calculate the returning beam pointing. The TSF KDP alignment reticle is inserted at the TSF plane. The automatic alignment system uses the Output Sensor in far field mode to view the reticle. The 1ω source is positioned at TSF pass-4, directed towards the Target Chamber. The final optics assembly, and thus the harmonic generator, is tilted so as to superimpose the reflection of the source on the reticular markings.

Then the 3ω source is inserted at the 3ω focus of final TSF lens. The Target Alignment Sensor is inserted, its location and orientation are verified with the CCRS. The equivalent target plane is viewed to determine 3ω beam aimpoint and spot size. LM8 is tilted to point the 3ω beam to the center of the target face, and LM4, LM5, LM7, and the final optics assembly are adjusted to correct any decentering or rotation or change of pulse angle of incidence at the tripler. The final optics assembly is inserted or retracted to achieve the correct spot size at the target face.



gure 15: The Chamber Center Reference Systems works as a high ?olution, large working distance alignment telescope. (a) The CCRS ?asures rotations using autocollimation. (b) The CCRS measures splacements using target mirrors.

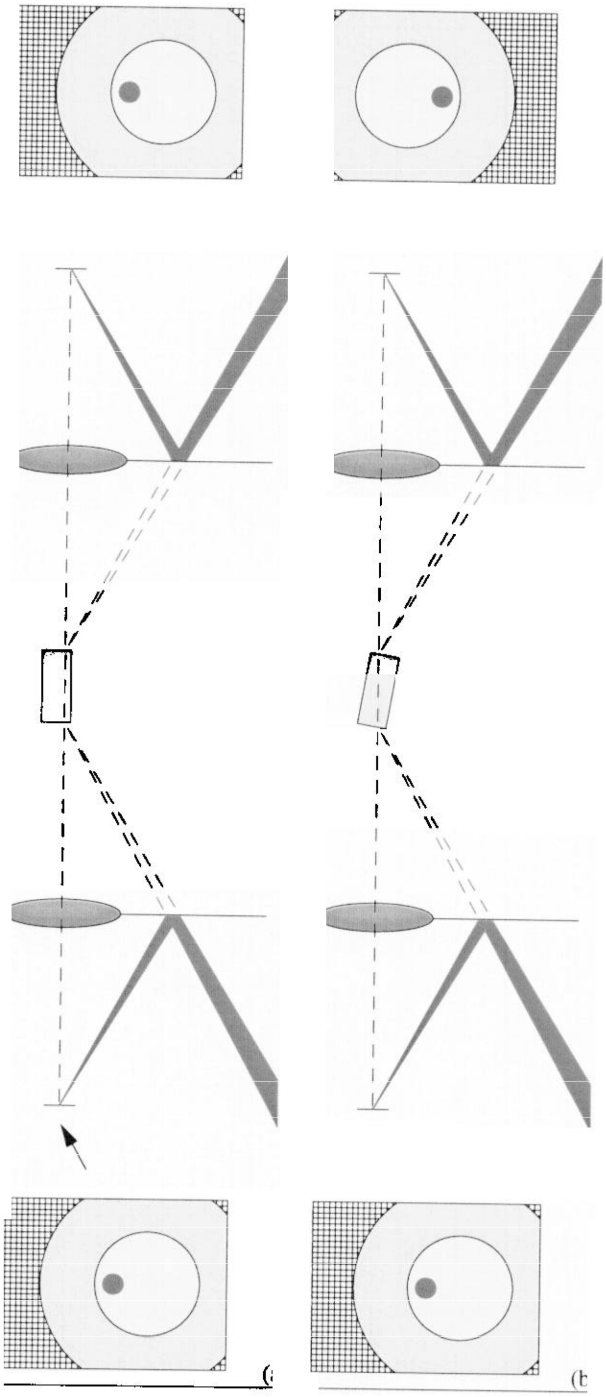
6. TARGET AREA ALIGNMENT



gure 16: Side view of TAS, CCD image from the upper TAS flector camera. (a) The target is centered in the TAS, and the cident beam is correctly pointed and focused. (b) The target is ntered in the TAS, but the correctly focused beam is mispointed. (c he target is centered in the TAS, but the beam is correctly pointed ı ıcorrectly focused.

Target chamber center will be established during initial NIF setup. Once that has been accomplished, the Chamber Center Reference System (CCRS) will be deployed. This system essentially consists of two identical alignment telescopes adjusted so that their optical axes intersect orthogonally at target chamber center. Once this relationship has been established, the telescopes will be locked in place.

The CCRS is used to locate and orient objects in the vicinity of target chamber center. It is be used during insertion of the Target Alignment Sensor (TAS) and some of the diagnostic apparatus. The CCRS operates in two modes as depicted in Figure 15.



gure 17: Side view of the TAS, CCD images from the 'per and lower TAS reflector cameras (a) The beams ai rrectly pointed and focused, but the target is decentere) The beams are correctly pointed and focused, but the 'get is tilted.

For TAS insertion, the CCRS operates in both modes. In the first, the orientation (rotation) of the TAS at target chamber center is measured by autocollimation. A reticle located at the focus of the CCRS objective is illuminated. The parallel rays emerge from the lens and propagate towards chamber center. Some reflect off a TAS mounted mirror target back into the CCRS objective. These rays form an image of the reticle at the focus of the CCRS objective. When the TAS is correctly oriented, the TAS mirror target normal is parallel to the incident rays and the image is exactly superimposed on the reticle. The images of the reticle with its reflection are analyzed, and rotation offsets are nulled by the motorized TAS positioner. In the second mode of operation, the location of the TAS is determined by targeting. The focal length of the CCRS objective is half the Target Chamber radius. The mirror target is a front surface mirror containing a target pattern that is not silvered, but frosted and translucent. This mirror is imaged onto a screen by the CCRS objective. Light from everywhere on the mirror surface except the frosted target pattern is transferred onto a coordinate map reticle via the 1:1 relay. A translatable camera views the reticle with high resolution. Thus each arm of the CCRS measures two rotations and two displacements of the TAS.

Target Alignment involves two steps. Aligning beams to an aimpoint and aligning targets to aimpoints. For most cases, the TAS is inserted, then the target is inserted. The TAS views the target. Feedback based on the TAS images is used to null location and orientation offsets of the target relative to TAS center and thus relative to the target chamber center defined by the CCRS. The 3ω alignment source is introduced in the TSF It travels through the beam transport into the Target Chamber onto the TAS CCD. The target face is imaged on the CCD. The beam is aimed at the center of the target face, but hits the TAS mirror and be reflected onto the CCD. TAS alignment is depicted in Figure 16-Figure 18. These figures show different focusing and pointing states for an alignment source and different locations and orientation of a NIF baseline hohlraum, and the resulting TAS camera images.

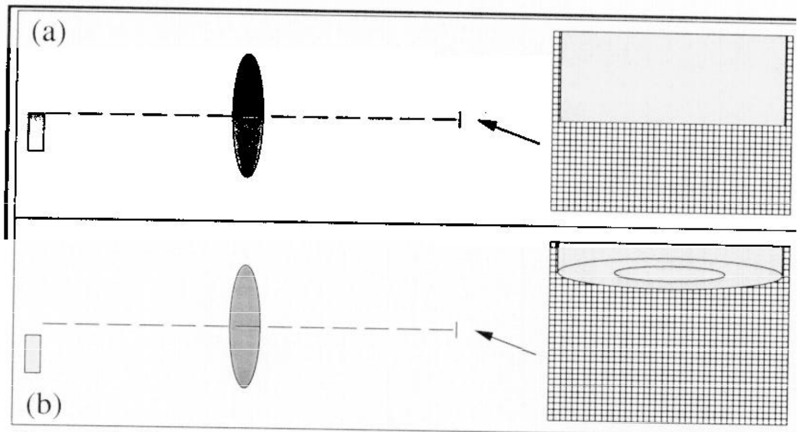


Figure 18: The target camera determines the longitudinal position of targets. It views targets from the side. The target camera's centerline lies in the focal plane of the top reflector camera. The is the plane in which the beams converge and in which the target face lies. (a) If the target face lies in this plane, and the TAS centerline passes through the center of each face, then no part of the face will be visible from the camera and the alignment system will observe a straight edge. (b) If the target face lies below the focal plane of the top reflector camera and/or if the target is tilted, part of the face will be visible and the alignment will observe some rounding of the target edge.

The beam hits the target's image on the CCD in the same place it would have hit the target. The spot size is measured and the lens is extended or retracted so as to be focused exactly at the target face. The mispointing is measured and LM8 is tilted to correct the mispointing. Once a beamline is aligned, its 3ω source will be removed and another beamline is aligned. The 3ω sources are intended to represent the shot time laser output. Authentication of these sources is performed using PAM shots. When the 4-pass is fired, pulses of sufficient irradiance to convert into TAS-detectable 3ω are produced. An alignment source is pointed to the center of the TAS camera, then removed from the TSF. A PAM shot is executed and the location of the resulting 3ω is recorded. If the 3ω alignment source and the PAM 3ω are offset from one another, an error condition is generated and the precision 3ω alignment source inserter will be adjusted so as to match the reference beam to the PAM pulse.

In some cases, beam to aimpoint/target to aimpoint alignment may occur. For example, cryogenic targets may not be inserted until moments before a shot. In this case, the beams will be aligned to aimpoints and when the target is brought in, its position and orientation are adjusted to match the TAS axis.

The TAS can also be used to verify target diagnostic alignment. A light source can extend from the TAS structure to the center of the TAS. The TAS cameras will verify that the light source is exactly in the center of the TAS. Then diagnostics can view the light source to ensure their own alignment. In cases where the TAS structure obstructs diagnostic line of sight to the center of the TAS, the light source can be mounted on the target positioner, inserted to the exact center of the TAS, and left there while the TAS is retracted. In this case, the light would be visible from everywhere in the Target Chamber.

7. SUMMARY

Many motorized mirror motions effect multiple aspects of alignment. The automatic alignment system will provide compensating commands for other motors in a such a way that each alignment task is accomplished without disturbing others.

Parallel alignment of the Pulse Generator, Main Laser and Beam Transport/Target Area will proceed much faster than a sequential alignment of the entire laser chain. All of the NIF beamlines will be aligned simultaneously. The TAS is the only sensor shared by the 192 beams. This sharing will not cause delays because the Beam Transport/Target Area alignment can commence almost immediately after a shot, whereas the Pulse Generators and Main Lasers cannot be aligned until significant cooling has occurred.

8. ACKNOWLEDGEMENT

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